Simulation from Proto to Model

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Abstract: - **The parameters necessary to establish similitude of sediment are Particle Reynolds number and Shields parameter .Sediment is scaled so that it can move in a corresponding manner both in the proto and model. Similarity between model and proto implies that Shield's parameter must be same in prototype and in the model. In addition Reynolds number should be equal in the model and the prototype. The accuracy of model study would depend upon realistic simulation of the distribution of suspended sediment on a vertical which is given by equation developed by Rouse. In free surface flow, gravity effects are predominant. Model – proto similarity is performed usually with Froude solitude. In modeling hydraulic structures, river Froude simulation is used.**

I. INTRODUCTION

A variety of bed materials such as sand, crushed coal, pumice, burnt shale, bakelite, sawdust, ground walnut shells, and different types of plastics have been used to replicate river bed sediment (Foster 1975). Sand and crushed coal has been used by the US Army Waterways Experiment Station (WES) to simulate the beds of different rivers (Sharp 1981.) Sand provides the advantage of being inexpensive and readily available. However, its use is impractical for the study of sediment movement in small models where the velocity of water is too low to move the sediment. In addition, ripples tend to form in the river bed due to the small grain size of the sand typically used (Sharp 1981). In addition, wet sand is heavy and hard to handle. In this paper, the use of sand as a bed material in model is tested.

II. PHYSICAL MODEL

Various types of models are used in research, including models of hydraulic structures. These hydraulic models have typically been classified into two categories, fixed bed models with non-erodible boundaries & no sediment transport and movable bed models (MBMs) Movable bed models are miniature streams that replicate the characteristics of related watercourses. The principles of similarity constitute the basis of the procedures involved in physical modeling. Given MBMs entail the existence of two phase flow (water and sediment), it follows that both water movement and sediment movement need to be modeled (Sharp, 1981).

III. SIMILITUDE

Similitude implies complete accord of various processes between a model and its prototype. Models can be similar to their prototypes in three different ways, namely, geometric similarity, kinematic similarity, and dynamic similarity. Geometric similarity implies that the shape of the model is the same as that of the prototype, whereas kinematic similarity signifies equality of ratios of velocity and acceleration. On the other hand, dynamic similarity means that the corresponding forces have similar ratio in the model and the prototype. In movable bed river models, because of lot of space for an undistorted model, the models are generally constructed as distorted model in which different scales for vertical and horizontal dimensions.

The parameters necessary to establish similitude of sediment are Particle Reynolds number and Shield's parameter

1. *Reynolds Number* = $Re^{*} = u_{*} D/\nu$

Which is the ratio of inertia force to the viscous force.

u_{*} = Critical shear velocity = $(g\ Y\ S_0)^{1/2}$ (m/sec)

Y = Depth of flow (m)

S_0 = Channel slope

D = Particle diameter (m)

ν = Kinematic viscosity of water (m^2/s)

2. *Shields Parameter* = $\tau^{*} = \rho\ u_{*}^{2} / \gamma' D$

$\gamma' = (\rho_s - \rho)$ = Submerged specific weight of sediment particle (N/m^3)

ρ = Mass density of water (kg/m^3)

IV. SEDIMENT MODELING

Sediment is scaled so that it can move in a corresponding manner both in the prototype and in the model. Similarly between model and prototype implies that Shield Parameter (τ^*) must be the same in the prototype and the model. In addition, the grain size Reynolds number (Re^*) should be equal in the model and the prototype. Sharp (1981) presented the following equations for scale ratios:

$$\tau^{*}_{r} = (u_{*}^{2} / (\gamma'/\gamma)D)_r = 1$$

$$(Re^{*})_r = (u_{*} D/\nu)_r = 1$$

A relationship is derived for the sediment size and density using above equations as follows:

$\gamma'_m / \gamma'_p = (u_{*m} / u_{*p})^2 * (D_p/D_m)$
$D_m/D_p = u_{*p} / u_{*m}$
Above equations give a relationship between particle size and specific weight.
$\gamma'_m / \gamma'_p = (D_p/D_m)^3$

General guidelines for the selection of model sediments

i. The model sediment must be denser than the model fluid;
ii. Individual sediment particles or low concentrations of particles should not float as result of surface tension forces;
iii. The particles should not break down or suffer alterations in size or shape due to abrasion or decay when transported;
iv. The model water visibility should not be reduced because of the discoloration of the media;
v. The sediment diameter should not be less than 0.7 mm otherwise the bed of the model forms ripples.

Simulation of bed material from Proto to Model for the river in Himalaya

CALCULATION FOR d_{50}

Parbati River

Input area of cross section in sq.m.	106.25
Input wetted perimeter of cross section in M	52.5
Input ‘n' value	0.045
Input slope	0.03363
Input d50 of proto in mm	54
Input Scale of model (GS)	100

Proto Caclulations

Hydraulic Radius R.	2.02381
Velocity in Proto	6.535587
Proto Tractive Force τ_p	68.06071
$\tau_p = \gamma R S$	
Critical Tractive Force τ_{cp} $\frac{\tau_{cp}}{(\gamma_S - \gamma_w) d_{50}} = 0.0$	5.346
Ratio τ_{p}/τ_{cp}	12.73115

Model Calculations

n in model $n_{proto}/(\text{Scale of model})^{0.16}$	0.021538
Velocity in model $Velo_{proto}/\text{scale of model})^{0.5}$	0.653559

Hydraulic Depth in model Using Mannings formula	0.021267
Model Tractive force $\tau_m = \gamma RS$	0.7152
Ratio Ratio = τ_m / τ_{cm}	12.73115
Therefore Critcal Tractive Force in Model	0.056177
Critical Tractive Force in Model τ_{cm} $\frac{\tau_{cm}}{(\gamma_s - \gamma_w) d_{50}} = 0.06$	
In above eqn d50 is unknown d50 in model	0.000567
d50 in model in mm	0.567446

Conclusion: In above river model sand of size 0.56 mm represent size 54mm in proto. Sand of size 2mm replicate the boulders present in proto So sand is suitable which is easily available and cheap,

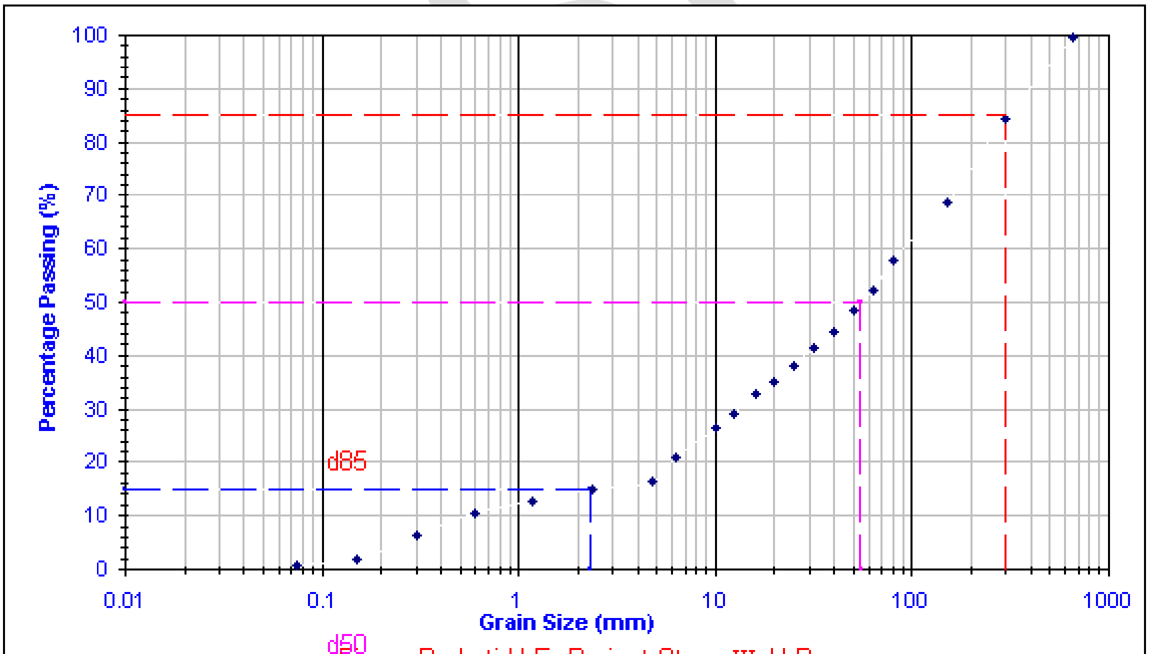

Figure-Parbati H.E. Project,Stage III, H.P.
Bed Material Gradation Curve (Proto)

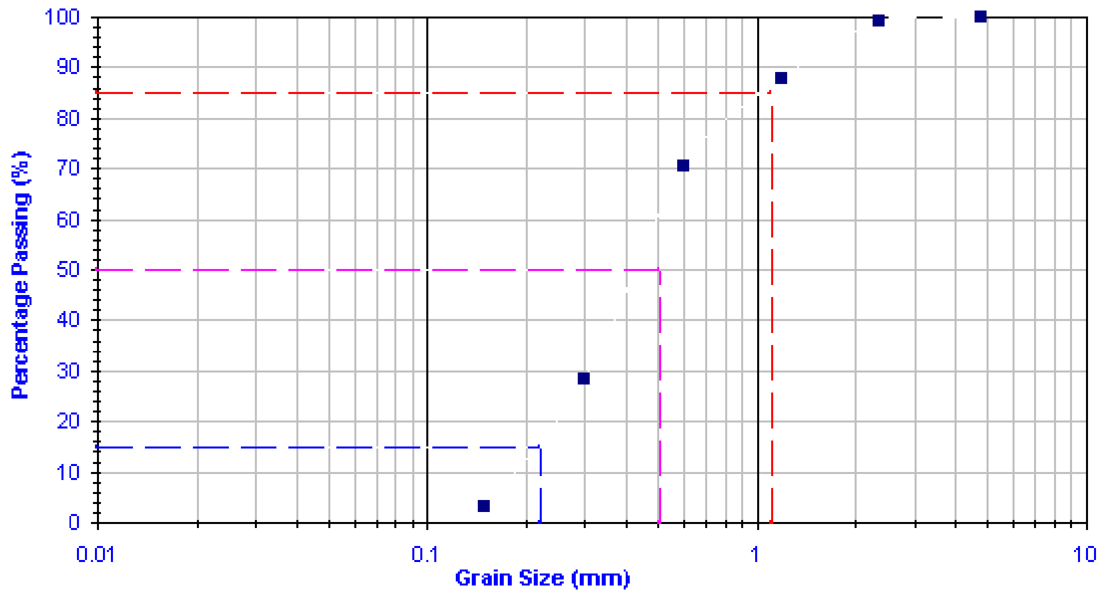

Figure -Parbati H.E. Project,Stage III, H.P.
Bed Material Gradation Curve (Used in Model)

Simulation of Suspended sediment in the model:-

The accuracy of the model studies would depend upon the realistic simulation of the distribution of the suspended sediment on a vertical which is given by following equation developed by Rouse.

$$\frac{C}{Ca} = \left(\frac{d-y}{y} * \frac{a}{d-a}\right)^{z}$$

Wherein

C = Concentration at depth "y" above bed level

Ca = Concentration at 0.05d above bed level

d = Depth of flow

y = depth at which concentration C is to be calculated

a = 0.05d

and $z = \frac{W}{K\sqrt{g.d.s}}$

where

w = Fall velocity of particles

K = Karman Constant

S = Water surface slope

Thus for proper simulation of the distribution of sediment on a vertical, 'Z" in model should be equal to 'Z" in prototype for corresponding diameter of the sediment,

$$Zm = \frac{Wm}{Km\sqrt{gm.d.msm}} = Zp = \frac{Wp}{Kp\sqrt{gp.d.psp}}$$

$$Wp = Wm\,\frac{Kp}{Km}\sqrt{\frac{gp\ dp\ sp}{gm\ dm\ sm}}$$

$\frac{kp}{km}$ and $\frac{gp}{gm}$ are equal to 1

Moreover in geometrically similar scale model

$$\frac{sp}{sm} = 1$$

Hence for geometrically similar models

$$Wp = wm\sqrt{\frac{dp}{dm}}$$

Thus a relationship between the diameter of low specific gravity material used in the model and that of the sediment in prototype can be worked out using above equation.

V. MODELLING FREE SURFACE FLOWS

In free surface flows(e.g. rivers , wave motion) , gravity effects are predominant . Model –prototype similarity is performed usually with a Froude similitude.

$$Fr_p = Fr_m$$

If the gravity acceleration is the same in both the model and prototype, a Froude number modeling implies that:

$$V_r = \sqrt{Lr} \qquad \text{(Froude similitude)}$$

VI. MODELLING HYDRAULIC STRUCTURES AND WAVE MOTION

In hydraulic Structures and Wave motion , the gravity effect is predominant in the prototype . The flow is turbulent and hence viscous and surface tension effects are negligible in prototype if the velocity is reasonably small. In such cases a Froude similitude must be selected

The most economical strategy is

1. To choose a geometrical scale ratio Lr such as to keep the model dimension small and
2. To ensure that the model Reynold"s number Re_m is large enough to make the flow turbulent at the smallest test flows.

VII. MODELLING RIVERS AND FLOOD PLAINS

In river modeling, gravity effects and viscous effects are of the same order of magnitude. For example , in uniform equilibrium flows (normal flows) , the gravity force component counterbalances exactly the flow resistance and the flow conditions are deduced from the continuity and momentum equations. In practice river models are scaled with Froude similitude equation and viscous effects are minimized. The model flow must be turbulent and with the same relative roughness as for the prototype.

VIII. CONCLUSION

In the present paper, the corresponding diameter of sediment in model is calculated by using Shield's criteria. A relationship between particle size and specific weight for the simulation is derived. Simulation of concentration of suspended Sediment is also given by using Rouse equation. Modelling of river, hydraulic structures are done with simulation of Froude number.